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THE ORTHODONTIC MOVEMENT OF TEETH (U) AND FORCE INST. OF

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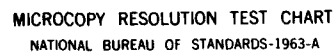
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BRIEF SUMMARY OF THESIS

alternating current

A pilot study was conducted using animal subjects that would determine if therapeutic transcutaneous electrical stimulation under the conditions tested would accelerate orthodontic tooth movement. The therapeutic range of transcutaneous electrical stimulation tested was an AC stimulation time setting which was continuous for 20 minutes or 1 hour of therapy per dog per day at a stimulation frequency of .5 Hertz and a current amplitude of 500 microamperes. Maxillary second premolars on mongrel dogs were protracted on edgewise sectional archwires using power chains. One side received transcutaneous electrical stimulation while the opposite side acted as a control.

Clinical tooth movement was enhanced in the 1 hour of therapy per day dog but not in the 20 minute per day specimens. X-ray comparisons showed no differences between the test and control sides in either group. Histological examinations revealed enhanced cellular activity in the 1 hour per day dog. Histologically, the 20 minute per day specimens and the control sides did not reveal any histological differences. The electron microprobe on the scanning electron microscope determined that the Ca/P ratios were also higher on the electrically stimulated sides than on the control sides. The Ca/P ratio of the tension side of the 1 hour per day dog was higher but in the 20 minute per day specimens the compression sides Ca/P ratios were higher when transcutaneous electrical stimulation was used in addition to orthodontic tooth movement.

Keyword: Thesis, ←

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THE EFFECTS OF TRANSCUTANEOUS ELECTRICAL STIMULATION
ON THE ORTHODONTIC MOVEMENT OF TEETH

by

Fred F. Nolan, Jr., B.S., D.D.S.

THESIS

Submitted in Partial Fulfillment of
the Requirements for the Degree of
Master of Science
at

THE UNIVERSITY OF TEXAS HEALTH SCIENCE CENTER AT HOUSTON
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(May, 1985)

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TABLE OF CONTENTS

	PAGE
INTRODUCTION.....	1
REVIEW OF THE LITERATURE.....	3
MATERIALS AND METHODS.....	12
RESULTS.....	17
DISCUSSION.....	38
SUMMARY.....	40
CONCLUSIONS.....	42
LITERATURE CITED.....	43
VITA.....	47
MASTER OF SCIENCE DATA SHEET.....	49

LIST OF TABLES

1. TABLE 1. ORTHODONTIC TOOTH MOVEMENT (mm)
RESULTS IN 49 DAYS 23
2. TABLE 2. CALCIUM/PHOSPHORUS RATIO'S OF
ALL SPECIMENS FROM A SEM ENERGY
DISPERSAL SPECTROMETER AND
MICROPROBE..... 25
3. TABLE 3. MEANS AND STANDARD DEVIATIONS OF
TENS 20 MINUTE/DAY SPECIMEN'S
CALCIUM PHOSPHORUS RATIOS. 25

LIST OF ILLUSTRATIONS

1.	FIGURE 1.	HISTOLOGICAL VIEW OF SPECIMEN #1, RIGHT SIDE OF ARCH, TENS 1 HOUR/DAY, MESIAL/COMPRESSION SIDE, X400 ZEISS MICROSCOPE AND CAMERA.....	27
2.	FIGURE 2.	HISTOLOGICAL VIEW OF SPECIMEN #1, RIGHT SIDE OF ARCH, TENS 1 HOUR/DAY, DISTAL/TENSION SIDE, X400.....	27
3.	FIGURE 3.	HISTOLOGICAL VIEW OF SPECIMEN #1, RIGHT SIDE OF ARCH, TENS 1 HOUR/DAY, MESIAL/COMPRESSION SIDE, SECOND SAMPLE, X400.....	29
4.	FIGURE 4.	HISTOLOGICAL VIEW OF SPECIMEN #1, RIGHT SIDE OF ARCH, TENS 1 HOUR/DAY, DISTAL/TENSION SIDE, SECOND SAMPLE, X400.....	29
5.	FIGURE 5.	HISTOLOGICAL VIEW OF SPECIMEN #1. LEFT SIDE OF ARCH/CONTROL SIDE, MESIAL/COMPRESSION SIDE, X400.....	31

6.	FIGURE 6.	HISTOLOGICAL VIEW OF SPECIMEN #1, LEFT SIDE OF ARCH/CONTROL SIDE, DISTAL/TENSION SIDE, X400.....	31
7.	FIGURE 7.	HISTOLOGICAL VIEW OF SPECIMEN #1, LEFT SIDE OF ARCH/CONTROL SIDE, MESIAL/COMPRESSION SIDE, SECOND SAMPLE, X400.....	33
8.	FIGURE 8.	HISTOLOGICAL VIEW OF SPECIMEN #1, LEFT SIDE OF ARCH/CONTROL SIDE, DISTAL/TENSION SIDE, SECOND SAMPLE, X400.....	33
9.	FIGURE 9.	HISTOLOGICAL VIEW OF SPECIMEN #2, LEFT SIDE OF ARCH/CONTROL SIDE, MESIAL/COMPRESSION SIDE, X400.....	35
10.	FIGURE 10.	HISTOLOGICAL VIEW OF SPECIMEN #2, LEFT SIDE OF ARCH/CONTROL SIDE, DISTAL/TENSION SIDE, X400.....	35
11.	FIGURE 11.	HISTOLOGICAL VIEW OF SPECIMEN #2, RIGHT SIDE OF ARCH, TENS 20 MIN./DAY, MESIAL/COMPRESSION SIDE, X400.....	37

12.	FIGURE 12.	HISTOLOGICAL VIEW OF SPECIMEN	
		#2, RIGHT SIDE OF ARCH, TENS	
		20 MIN./DAY, DISTAL/TENSION	
		SIDE, X400.....	37

INTRODUCTION

The orthodontic profession is increasingly presented with different treatment modalities that may be effective adjuncts to present day treatment. Historically, mechanical means have been employed to accelerate physiological orthodontic tooth movement, predominantly using elastics, headgears, and various archwires and appliances.

Orthodontic appliances are effective in producing desired tooth movement and thus eliciting an improved functional occlusion and esthetic result. Occasionally the clinical orthodontist is faced with an impacted cuspid or similar tooth which is very hard to move orthodontically. The rationale behind this research is to use a proven modern orthodontic technique and appliance to orthodontically move teeth, just as an orthodontist would in clinical practice, and see if the agent being tested may be of benefit in difficult cases.

In search of accelerating physiological orthodontic tooth movement, investigators have used many chemical and physical agents, including heat¹, parathyroid hormone (PTH)², vitamin C³, and electricity⁴ in conjunction with mechanical forces to enhance orthodontic tooth movement. These studies suggest that electricity may be a useful tool in clinical trials of orthodontic tooth movement. When other agents such as hormones⁵ and drugs⁶ were used the reports suggested

their effects were not limited to the teeth and alveolar process but affected target cells systemically throughout the body. Locally applied electricity has been found to be noninvasive and exert its effect only in the tissues adjacent to the surface electrodes.

The purpose of this pilot study is to determine if therapeutic transcutaneous electrical stimulation using an alternating current through surface electrodes would enhance mechanical orthodontic tooth movement, and if so, to use this modality as a treatment of choice.

REVIEW OF THE LITERATURE

Although there have been no reported investigations on the effects of transcutaneous electrical neurostimulation (TENS) as a modality in orthodontic tooth movement in the literature, there has been extensive research on the nature of the supporting tissues undergoing orthodontic tooth movement, the electrical activity of living tissue, and how the application of electrical current may influence this behavior. Transcutaneous electrical nerve stimulation is an alternating electrical current applied to the skin or gingiva with surface electrodes. Many researchers have reported the use of TENS as a treatment modality in pain control. Cauthen (1975)⁷, Ebersold (1975)⁸, and Picaza (1975)⁹ reported on the clinical effectiveness of transcutaneous electrical neurostimulation (TENS) for chronic pain states. TENS has been used primarily thus far for pain control. Kirsch (1974)¹⁰ found that placing electrical stimulators about peripheral nerves is safe and in fact may be a very rewarding method of relief of chronic pain. Kirsch reports patients having pain relief from the utilization of TENS, rather than from surgically implanted electrical stimulators. Kirsch also reports electroencephalograms (EEG) on patients being treated with neurostimulators found that during the

experience of pain relief and transcutaneous electrical stimulation, the EEG asymmetries disappeared in the neural tissue. Kirsch found that the spectral analysis of the EEG provided a "neurophysical marker" to study patients being treated with nerve stimulators. Kirsch found it of interest that in one patient that exhibited no change in the EEG there was no pain relief from electrical stimulation. K.C. Ullis (1983)¹¹ refers to TENS as a noninvasive method of electrotherapy that uses a pulsed alternating current (A.C.) biomedically engineered to maximize stimulation of the large myelinated A beta neurons while minimizing both muscle contraction and unmyelinated C fiber response. This mechanism utilizes the theory described by Melzak and Wall (1965)¹², the Gate Control Theory of Pain, and is reported to cause hyperexcitation of the interneurons in the substantia gelatinosa which inhibits the transmission of C fiber information to the secondary afferent neurons, inhibiting pain. Ullis (1983)¹¹ reports that in using TENS on his subjects the human body performs as an "organic battery" and all living cells of the body are tiny bio-electric units. The bioelectricity of living cells and their components is well documented in research literature. Rodan (1978)¹³ reported that the cell membranes of cartilage cells are effected by electrical fields by agitation of cell membrane potentials causing

fluxes of sodium and calcium across the cell membranes. Rodan found that the electrical field affects enzyme systems within the cell and increases concentrations of cyclic adenosine 3'5' monophosphate. Rodan found that appropriate electrical stimulation would increase cellular metabolism. Electrical stimulation of cellular metabolism during orthodontic tooth movement may affect the rate of this movement.

Storey (1973)¹⁴ in his work with guinea pigs reported that the rate of removal of bone by resorptive processes depends on the rate of cellular activity and the extent of surface area available for resorption. Mechanical forces can move teeth to new positions because of their ability to stimulate local cellular responses in the periodontal ligament and alveolar bone. Light orthodontic forces achieved a slower but steadier tooth movement, better quality bone formation, and less relapse. Reitan (1957)¹⁵, (1964)¹⁶ and Storey (1973)¹⁴ both found that under heavy pressure the blood vessels under compression are no longer open, but with light pressure, endothelial cells adapt to low continuous pressure like other cells. DeAngelis (1970)¹⁷ suggests that the transducing element responsible for the coordinated bone changes may be found in the piezoelectric nature of bone. Bone is said to have piezoelectric (piezo - from the Greek word meaning "pressure") properties

primarily due to its collagenous composition as reported by Fukada and Yashuda (1957)¹⁸ and Bassett (1962)¹⁹, (1968)²⁰. DeAngelis notes that the crystalline structure of collagen is therefore capable of polarizing electrical charges when distorted. He reports bone bending or distortion is the trigger mechanism and may be found in the microscopic bending of the alveolus by orthodontic force. Picton (1965)²¹ and Baumrind (1969)²² have shown that the alveolus could be distorted or bent with remarkably little force. By this distortion, DeAngelis reports that alteration of electrical environment locally may regulate differentiation of bone progenitor cells near surfaces receiving varying stresses. Bassett (1964)²³, (1968)²⁰ reports evidence that convex surfaces differ in electric charge from concave surfaces when under compression due to various stress patterns. This factor, DeAngelis (1970)¹⁷ states, could explain cellular changes on distant bone surfaces effected by a stimulus through distortion, while not directly contacting the stimulus. In fact he reports that since dentin has been shown to have piezoelectric properties also due to its collagen content as suggested by Shamos and Levine (1967)²⁴ Bassett's (1962)¹⁹ work was supported by both Steinberg (1973)²⁵ and Marion (1971)²⁶. Their studies suggest the possibility that electrical currents are generated within stressed tissues acted on by

mechanical forces and Bassett (1968)²⁰ stated that macromolecules which interact with specific sites in cell membranes may be charged by electrical currents. Rodan's (1978)¹³ studies supported the work of Mueller (1975)²⁷ in that both researchers found that electrical currents mobilized ions across cell membranes. Rodan's (1978)¹³ work is very important in that he suggested that calcium and sodium were responsible for the enhancement of the incorporation of H-thymidine into DNA upon stimulation of chick chondrocytes in vivo within oscillating electrical fields. Rodan showed that calcium and sodium were affected by electrical currents at a cellular level. In addition to other cellular effects of electrical currents, Rodan noted that there were changes in the level of cyclic AMP.

Research involving orthodontic tooth movement and bone bending have resulted in studies relating tooth movement on a cellular level to the electrical potential of living tissues. Zengo's (1973)²⁸, (1974)²⁹ studies were of particular importance in describing the "piezoelectric" phenomenon. Deforming forces were applied to teeth and their supporting structures, both as integral mechanical units of all the teeth in the denture and as component parts (that is, enamel, dentin, cementum, and alveolar bone) of each individual tooth. Zengo's study was done in vitro (1973) and in vivo (1974) on beagle dogs. Both

the amplitude and polarity of the resultant charge separation (voltage or potential difference) were recorded from a variety of sites about many teeth, and a "charge-polarity map" was obtained. A comparison between the "maps" and the cellular responses known to occur during orthodontic procedures produced correlations which were consistent with previous studies on long bones. Areas that have been described as characterized by osteoblastic activity were routinely electronegative and, conversely, areas of positivity or electrical neutrality were observed in regions characterized by osteoclasia during orthodontic tooth movement. The presence of attached gingiva in the in vivo study played a role in affecting the electrical polarization found on teeth adjacent to a stressed tooth. Zengo found the attachments of the stressed tooth displaced the adjacent teeth sufficiently to elicit an electrical response on the surface of their crowns. Zengo concluded that small voltages could be measured in teeth at a greater distance from the principal site of deformation.

For the past twenty years, researchers and clinicians have used exogenous electrical currents in successful treatments to initiate osteogenesis in both fractured and intact bones. Particularly significant research was done by Brighton (1975)³⁰, (1977)³¹ and Friedenbergl (1970)³², (1977)³¹. Both researchers used direct current stimulation

to treat nonunion fractures. Brighton and Friedenberg working together, demonstrated that when electrodes are placed into bone, resorption will occur around the positive electrode (anode) and osteogenesis will occur around the negative electrode (cathode) when the current level is between 5 and 20 microamperes. Yasuda (1974)³³ reported increased bone apposition and callus density using exogenous electrical currents in treating uncomplicated fractures.

As the interest in stimulating osteogenesis with exogenous electrical currents developed, researchers began to use different types of electrical currents to test cellular activities. Brighton and Friedenberg (1974)³⁴ found that direct electrical currents at the cathode (positive electrode) site caused differences in oxygen consumption and alterations in tissue pH. Peck (1973)³⁵ and Nagata (1975)³⁶ using rats, and Davidovitch (1977)³⁷ using cats, employed direct galvanic currents. Cyclic nucleotides were selected as the main target of their investigations because they are considered to be intracellular "second messengers" in the action of specific bone cell activators, such as parathyroid hormone and calcitonin on their target cells.

Davidovitch and his associates have done comprehensive studies on the effects of direct continuous currents. Using immuno-histochemical techniques, Davidovitch (1980)^{4,38} found external electrical currents increased

bone and periodontal ligament cyclic nucleotide contents, a step leading toward heightened enzymatic phosphorylation reactions, synthetic and secretory activities, and an enhanced rate of tissue remodeling. In previous studies, Davidovitch (1975)³⁹, (1978)⁴⁰ studied the involvement of adenosine 3'5' monophosphate (cyclic AMP, cGMP) in the periodontal tissue response to orthodontic treatment and concluded that mechanical forces might not be the most efficient means to activate periodontal ligament and alveolar bone cells. This conclusion, coupled with his recent observation that electric current can activate a large number of cells in a well-delineated area, Davidovitch (1980, I)⁴, reported that the application of electrical currents to periodontal tissues during orthodontic treatment will potentiate the effect of mechanical forces and lead to an enhanced rate of cell activation, tissue remodeling, and tooth movement. Davidovitch (1980, II)³⁸ then studied the rate of tooth movement in cats treated only by mechanical forces that tipped their maxillary canines distally and in others receiving electric stimulation in addition to the mechanical forces applied to orthodontically treated canines. Teeth treated by force and electricity moved significantly faster than those treated by force alone. Histologic examination of the involved tissues revealed that the enhanced tooth movement

resulted from resorption of bone as a result of the compression force and the presence of the anode near the periodontal ligament compression site. The degree of new bone formation (as judged by the length of the newly formed bony trabeculae in the periodontal ligament) at electrically treated tension sites was higher than at the corresponding sites of teeth treated by force alone. Examination of the involved tissues by an immunohistochemical technique designed to localize cyclic nucleotides in cells revealed that the cellular response to the combined force-electric treatment was more pronounced than the response to force alone. Davidovitch's results suggested that orthodontic tooth movement may be accelerated by the use of force in conjunction with other biologically potent means which can generate a local response.

MATERIALS AND METHODS

In this study, dogs were used because their adaptable disposition, dental occlusion and oral anatomy are all very favorable for the use of orthodontic appliances and/or electrical currents. The dog's occlusion allows an orthodontic appliance to be used on the maxillary arch without occlusal interference from the mandibular teeth. The maxillary canines are large teeth which are excellent orthodontic anchorage units. There was sufficient space to bring the second premolar forward after removal of the very small maxillary first premolar. In addition, the gingival tissue in a dog is very thin allowing the underlying alveolar bone to be stimulated from noninvasive surface electrode pads. Thus, the clip-on electrodes fitted with hypo-allergenic sponges come to lie very near the alveolar bone providing a short electrical current path.

The four dogs used in this experiment were adult females weighing 30-40 pounds. At one to one and a half years of age the dog's permanent dentition is fully erupted. The dog's maxillary premolar and canine calcification and root formation are complete at this developmental stage and can be compared with young adult human beings which make up the bulk of clinical orthodontically treated patients.

Initial treatment consisted of the extraction of the maxillary right and left first premolars and bonding of the maxillary canines and second premolars. Each animal was anesthetized by induction with a 1.5cc anesthetic mixture, Ketamine (100mg/cc), Xylazine (100mg/cc), and Acepromazine (10mg/cc), intubated and maintained on a 50-50 mixture of N₂O and O₂ plus 1 to 1.5% Methoxyfluorane (Metofane). The buccal surfaces of the teeth were contoured with a high speed diamond bur, acid etched for 3 minutes and glazed for better bracket adaptation. The brackets (.022 Dyna-lock, Unitek) were attached with Concise bonding cement (3-M Corporation). Yellow Elgiloy 0.016 X 0.022 inch sectional archwires (Rocky Mountain) were constructed so that the second premolars could be moved mesially without excessive tipping. Elastic ligatures attached the archwire in the brackets so that the force holding the archwire on the bracket was the same, and the elastic ligature could be removed easily for brushing the teeth. Approximately 150 grams of elastic force was used for protraction by a Rocky Mountain Closed Elastic Energy Chain (Rocky Mountain Orthodontics; J-120, J-121, and J-122) and were measured accurately in 1.0 millimeter increments on the Instron Universal testing instrument and graphed. The exact forces were then interpolated from the graph. Each day the amount of tooth

movement was measured with a ruler. The power-chains were changed every two weeks as the distance between the premolars and canines shortened, thus keeping a relatively constant force for tooth movement. Intraoral x-rays and photographs were taken before, during and upon completion of treatment.

The instrument that was used to provide the alternating electrical current in this research project was the Alpha-Stim 2000 (Dyna Flex International). Two electrodes fitted with hypoallergenic sponges were clipped on over the buccal and palatal gingiva, distal to the protracting premolar and mesial to the extraction site. Transcutaneous electrical stimulation was applied to the right arch of each dog; and the left arch, receiving the same mechanics, acted as the control. Dog #1 had both maxillary first premolars removed, both second premolars protracted and electrical stimulation (TENS) on the right side for one hour a day for 49 days. Dogs #2 and #3 had both maxillary first premolars removed, both second premolars protracted and electrical stimulation on the right side for 20 minutes a day for 49 days. Dog #4 had both maxillary first premolars extracted but no braces and electrical stimulation on the right side for 20 minutes a day for 49 days to examine the effects of transcutaneous electrical stimulation with

extractions but no mechanical force applied to move the teeth.

In this experiment, the treatment mode for the Alpha-Stim 2000, Modality A, was provided by a power source of six 6-volt (2.6 amp-hour rechargeable Gel Cells, Electromedical Products, Inc.). Modality A is a pre-timed low level AC stimulation that measures impedance reduction as a means of indicating electrical contact and penetration for bioconductive therapy. A stimulation time setting for this experiment was continuous for 20 minutes or 1 hour of therapy per dog per day at a stimulation frequency of 0.5 Hertz (cycles per second) and a current amplitude of 500 microamperes with clip-on electrode pads for application of current. The Modality A treatment waveform that was used is a biphasic, nonsinusoidal, complex waveform within a modified square wave envelope.

Forty-nine days after tooth protraction, the dogs again underwent general anesthesia and the maxillary second premolars immediately distal to the canines were removed in block sections with the surrounding alveolar bone. The block sections were fixed in 10% Buffered Formalin solution for 48 hours. The teeth and surrounding bones were sectioned mesio-distally with a diamond saw (Buehler Corporation). The buccal halves of the sections

of tissue blocks were dehydrated in 70%, 95%, 95%, 100%, 100% alcohol (30 minutes each) and 30 minutes in Freon (N_2), followed by critical-point freeze drying and embedding in Buehler Epoxy Hardner and Resin (Buehler Corporation). Then the epoxy-embedded specimens were polished, coated with carbon, and analyzed for calcium/phosphorus ratios using an electron microprobe on a scanning electron microscope (Camecha Microprobe Electron Microscope, Tracor Northern Computer, Energy Dispersal Spectrometer and Microprobe) to evaluate bone remodeling.

The tissue blocks of the lingual halves were prepared for histological sectioning and viewing. The clinical crowns were removed from all tissue blocks in order to facilitate decalcification. Tissue blocks were placed in formic acid for two weeks to decalcify, embedded in paraffin, sectioned and mounted. Sections were stained with H & E, or PAS or Masson's Trichrome. The stained specimens were studied and representative regions of alveolar bone, periodontal ligament and cementum were photographed. All photographs were taken from the middle one third of root (approximately midway between the apex and cervix of the tooth).

RESULTS

CLINICAL MEASUREMENT OF TOOTH MOVEMENT (49 DAY RESULTS)

ILLUSTRATED IN TABLE I.

Dog #1 was electrically stimulated on the right side for 1 hour/day and showed 4.5 millimeters of tooth movement on the right side and 3 millimeters of tooth movement on the left control side, both sides having identical orthodontic mechanics and first premolar extractions.

Dog #2 was electrically stimulated on the right side for 20 minutes a day and showed 2.5 millimeters of tooth movement on the right side and 2.1 millimeters of tooth movement on the left control side, both sides having identical orthodontic mechanics and first premolar extractions.

Dog #3 was electrically stimulated on the right side for 20 minutes a day and showed 2.0 millimeters of tooth movement on the right side and 2.1 millimeters of tooth movement on the left control side, both sides having identical orthodontic mechanics and first premolar extractions.

Dog #4 was electrically stimulated on the right side for 20 minutes a day and had first premolar extractions but no orthodontic appliances or forces were used on either

side and showed 0.2 millimeters of mesial drift on both the right side and the left control side.

HISTOLOGY

ILLUSTRATED IN FIGURES 1-12

Histological examination of the tissue samples revealed no significant differences between the teeth and support tissues that received electrical stimulation for 20 minutes a day and the control sides (Dogs #2,3,4; FIGURES 9,10,11,12). The normal microscopic tissue alterations were observed in these specimens that were moved orthodontically (Dogs #2,3; FIGURES 9,10,11,12). The compression sides (the direction in which the teeth were being moved; FIGURES 9,11) had normal osteoclastic activity with the normal resorption of the alveolar bone. The tension side (the direction the teeth were being moved from; FIGURES 10,12) showed osteoblastic activity with new normal bone deposition. In Dog #1, the specimen that was electrically stimulated for one hour a day on the right side, enhanced cellular activity was noted on the tension (FIGURES 2 & 4) and compression (FIGURES 1 & 3) sides (mesial and distal midpoints of the roots) as compared with the 20 minute a day specimens (FIGURES 9,10,11,12) or the control/left sides (FIGURES 5,6,7,8) of the 1 hour a day stimulated specimens. In H & E stained sections, a greater

amount of osteoclastic activity was noted on the compression side (FIGURES 1 & 3). The alveolar bone was more irregular at the interface with the periodontal ligament (note arrows in FIGURES 1 & 3), where osteoclastic activity was taking place on the compression side, than on the right sides of the 20 minute a day stimulated specimens (note arrows in FIGURE 11) or the control sides (note arrows in FIGURES 7 & 9). On the tension side (distal root midpoint; FIGURES 2 & 4) osteoblastic activity appeared to be enhanced in the one hour per day specimen. H & E, PAS and Trichrome stained specimens that were examined showed a more wavy and spiculed appearance of both the periodontal ligament (note arrows in FIGURES 2 & 4) and the new alveolar bone which the osteoblasts were laying down. Significantly, the left/control side of Dog #1 showed normal osteoblastic and osteoclastic activity (FIGURES 5,6,7,8). In the specimens examined, there were no pathological changes evident in the teeth receiving electrical stimulation

THE CALCIUM (Ca)/PHOSPHORUS (P) RATIOS

ILLUSTRATED IN TABLES 2 AND 3

The Calcium (Ca)/Phosphorus (P) ratios of the alveolar bone process adjacent to the periodontal ligaments were determined at the root midpoints. In the specimens that were electrically stimulated for 20 minutes per day on the right

side of the arch, the mesial or compression sides of the alveolar bones being resorbed showed a slightly higher ratio ($\text{Ca/P} = 1.99 \pm .103$) compared to the new bone being deposited on the tension side, the distal ($\text{Ca/P} = 1.93 \pm .096$). On the left side of the arch of these specimens, the control sides which were not electrically stimulated, the compression side of the alveolus, the mesial ($\text{Ca/P} = 1.96 \pm .081$), showed a slightly higher ratio compared to the tension side, the distal ($\text{Ca/P} = 1.91 \pm .118$). Also, both the tension ($\text{Ca/P} = 1.93 \pm .096$) and the compression ($\text{Ca/P} = 1.99 \pm .103$) sides Ca/P ratios were slightly higher on the electrically stimulated specimens right side of the arch compared to the tension ($\text{Ca/P} = 1.91 \pm .118$) and compression ($\text{Ca/P} = 1.96 \pm .081$) sides of the left, control sides of the arch.

The specimen that received electrical stimulation for one hour per day on the right side of the arch also showed higher ratios on the tension side ($\text{Ca/P} = 2.02746$) and the compression side ($\text{Ca/P} = 1.99798$) as compared to its left control side of the arch's tension ($\text{Ca/P} = 1.99002$) and compression ($\text{Ca/P} = 1.93625$) sides of the tooth being moved. The Ca/P ratios however, in this specimen appeared slightly higher on the new bone deposition side where osteoblastic activity was taking place, the tension side,

rather than on the mesial, compression side, undergoing resorptive osteoclastic activity as seen in the 20 minute per day stimulated specimens.

TABLE 1. ORTHODONTIC TOOTH MOVEMENT (millimeters) RESULTS
IN 49 DAYS.

Results shown of clinical tooth movement in vivo on dogs using conventional orthodontic appliances to protract maxillary second premolars toward the cuspids on the right and left sides of the arch. Specimens underwent orthodontic treatment for 49 days under controlled conditions.

ORTHODONTIC TOOTH MOVEMENT

(millimeters)

RESULTS IN 49 DAYS

DOG #	TENS TIME	RIGHT/ TENS SIDE	LEFT/ CONTROL SIDE
1	1 HOUR/DAY	4.5	3.0
2	20 MIN./DAY	2.5	2.1
3	20 MIN./DAY	2.0	2.1
4	20 MIN./DAY	0.2	0.2

TABLE 1.

TABLE 2. Ca/P RATIOS OF SPECIMENS

Comparisons of 1 hour per day TENS specimens right/TENS and left/control sides of the arch and mesial/compression and distal/tension sides of the protracting maxillary second premolars. Camecha Microprobe Electron Microscope, Tracor Northern Computer, Energy Dispersal Spectrometer and Microprobe.

TABLE 3. MEANS AND STANDARD DEVIATIONS OF TENS 20 MINUTE/DAY SPECIMEN'S Ca/P RATIOS

Comparisons of the right/TENS and left/control sides of the arch, and mesial/compression and distal/tension sides of the protracting maxillary second premolars in the 20 minute per day TENS specimens.

Ca/P RATIO'S OF SPECIMENS

SPECIMEN	SIDE OF ARCH	TENS TIME/DAY	MESIAL/ COMPRESSION SIDE	DISTAL/ TENSION SIDE	COMPARISON
1	Right	1hr.	1.99798	2.02746	D>M
	Left	None	1.93625	1.99002	R>L
2	Right	20min.	1.87776	1.83914	TABLE 3
	Left	None	1.87890	1.80256	
3	Right	20min.	2.01382	1.92261	TABLE 3
	Left	None	1.98658	1.89940	
4	Right	20min.	2.07892	2.03066	TABLE 3
	Left	None	2.03967	2.03888	

TABLE 2.

MEANS AND STANDARD DEVIATIONS OF TENS 20 MINUTE/DAY SPECIMEN'S Ca/P RATIOS

SIDE OF ARCH	MESIAL/ COMPRESSION SIDE	DISTAL/ TENSION SIDE	COMPARISON
RIGHT/TENS	1.99017 [±] .103	1.9308 [±] .096	M>D
LEFT/CONTROL	1.96838 [±] .081	1.91361 [±] .118	R>L

TABLE 3.

FIGURE 1. Histological view of specimen # 1's maxillary right arch was electrically stimulated (TENS) for 1 hour per day, showing the mesial/compression side of the tooth undergoing orthodontic tooth movement. The arrows point to enhanced osteoclastic cellular activity at the periodontal ligament (P) alveolar bone (B) interface. X400, H & E stain, root midpoint, (C) cementum.

FIGURE 2. Histological view of the distal/tension side of the same tooth as in FIGURE 1. The arrows point to enhanced osteoblastic activity noted by wavey trabecular pattern of the newly formed bone. X400, PAS stain, root midpoint.



FIGURE 3. Histological view of the mesial/compression side of the same tooth as in FIGURE 1. The arrows point to another area of enhanced osteoclastic cellular activity at the periodontal ligament (P)/alveolar bone (B) interface. X400, Trichrome stain, root midpoint, (C) cementum.

FIGURE 4. Histological view of the distal/tension side of the same tooth as in FIGURE 1. The arrows point to enhanced osteoblastic activity noted by the wavy trabecular pattern of the newly formed bone. X400, Trichrome stain, root midpoint.



FIGURE 5. Histological view of specimen # 1's maxillary left/control arch which received only orthodontic force, showing normal cellular activity at the periodontal ligament (P) alveolar bone (B) interface's mesial/compression side of the tooth. X400, Trichrome stain, root midpoint, (C) cementum.

FIGURE 6. Histological view of the distal/tension side of the same tooth as in FIGURE 5. The arrow points out normal osteoblastic activity and no wavey trabeculae. X400, H & E stain, root midpoint.



FIGURE 7. Histological view of the mesial/compression side of the same tooth as in FIGURE 5. The arrow points out normal osteoclastic cellular activity at the periodontal ligament (P)/alveolar bone (B) interface. X400, H & E stain, root midpoint, (C) cementum.

FIGURE 8. Histological view of the distal/tension side of the same tooth as in FIGURE 5. The arrow points out normal orderly osteoblastic activity between the periodontal ligament (P)/alveolar (B) bone interface. X400, Trichrome stain, root midpoint.

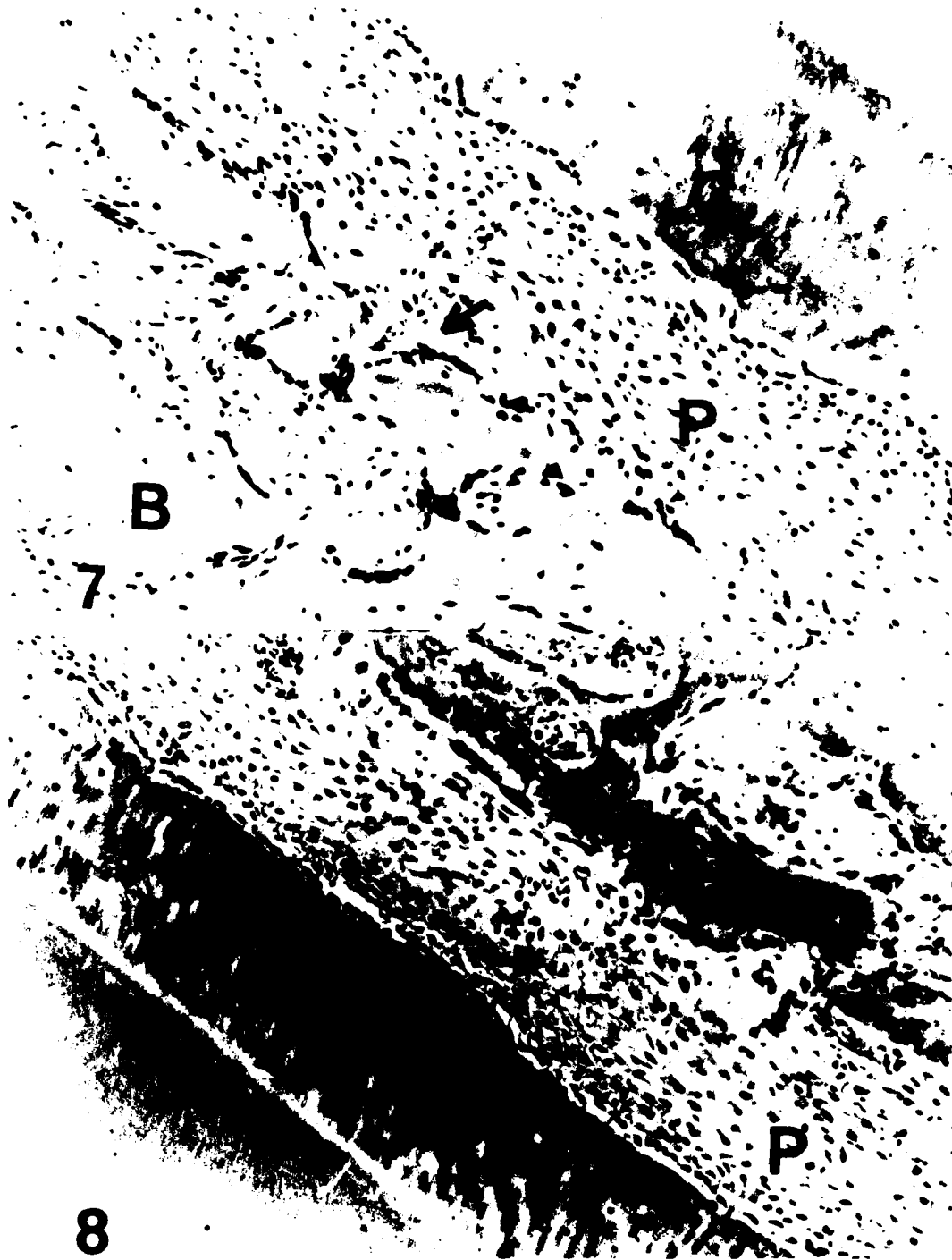


FIGURE 9. Histological view of the mesial/compression side of the tooth on the control/left side of the maxillary arch of specimen #2. The arrow points to normal cellular activity at the periodontal ligament (P)/alveolar bone (B) interface. X400, H & E stain, root midpoint, (C) cementum.

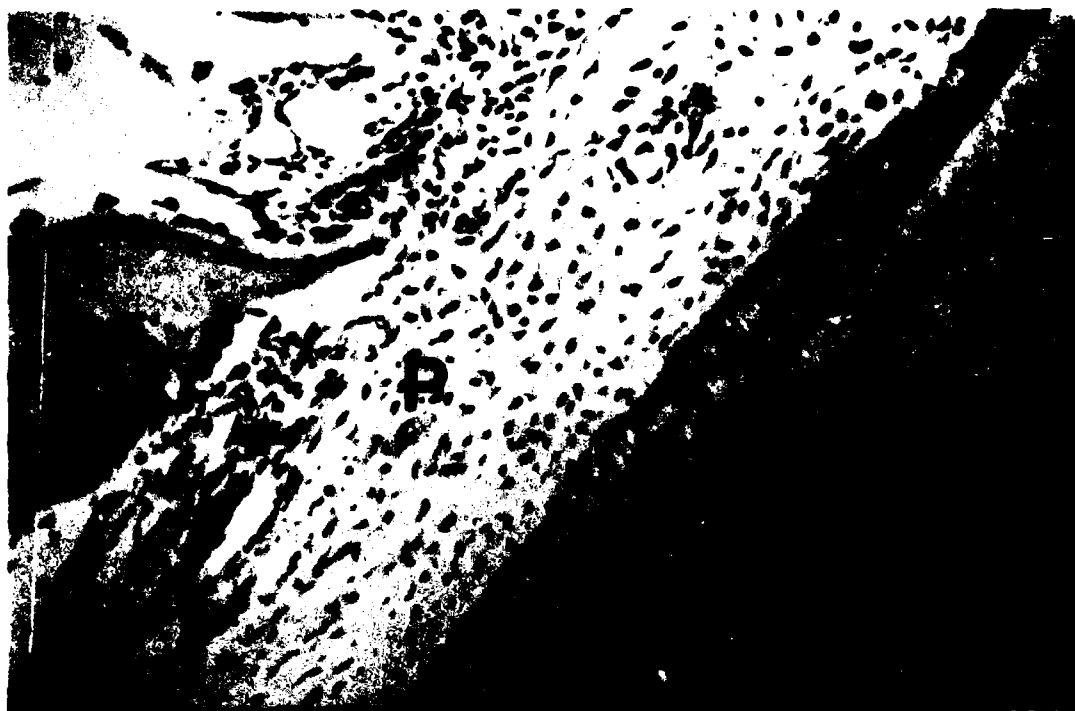
FIGURE 10. Histological view of the distal/tension side of the same tooth as in FIGURE 9. The arrow points to normal osteoblastic cellular activity (B) interface. X400 Trichrome stain, root midpoint.



10.

FIGURE 11. Histological view of the mesial/compression side of the tooth on the right/20 minute per day electrically stimulated (TENS) side of specimen # 2's arch. The arrow points to normal cellular activity at the periodontal ligament (P)/alveolar bone (B) interface. X400, H & E stain, root midpoint, (C) cementum.

FIGURE 12. Histological view of the distal/tension side of the same tooth as seen in FIGURE 11. The arrow notes an orderly appearance of the periodontal ligament (P) and normal osteoblastic activity. X400, H & E stain, root midpoint.



DISCUSSION

The results of this research revealed that transcutaneous electrical stimulation may enhance orthodontic tooth movement using an electrical alternating current of 0.5 Hertz frequency and 500 microamperes amplitude for one hour per day. The twenty minute per day specimens exhibited no differences in the amount of tooth movement or the histological results. These results indicated that a large study covering longer ranges of time and/or more repetitions during the day are needed to examine all possibilities of transcutaneous electrical stimulation in vivo in orthodontic tooth movement.

This study was limited by small sample size due to the time requirements for therapy and the expense of animal care. The specimen that was electrically stimulated for one hour per day exhibited a 50% increase in tooth movement, enhanced cellular activity on the tension and pressure sides of the periodontal ligament, and slightly higher Ca/P ratios than those of the 20 minute per day specimens and the controls.

This study was based upon a previously established methodology for studying the effects of different modalities, in this case transcutaneous electrical stimulation,

on orthodontic tooth movement. The techniques had been proven to establish an accurate, sophisticated analysis of the effects of unknown therapeutics on orthodontic tooth movement.

The orthodontic forces (approximately 150 gms.) were within the range used by Storey (1973)¹⁴. Tooth movement within different breeds of dogs may vary and therefore the control side of each dog, being the opposite arch, was important in obtaining accurate comparative results. The author feels that due to the variable rate that teeth move in vivo that the significance of tooth movement shown in this study is not great, but that the difference in the histology and Ca/P ratios in the one hour per day specimen and the 20 minute per day specimens warrant further study.

SUMMARY

A study using an established orthodontic technique to determine if therapeutic transcutaneous electrical stimulation would enhance orthodontic tooth movement in dogs was performed. Mongrel dogs of the same sex and age group had maxillary first premolars removed and maxillary second premolars protracted on edgewise sectional archwires using power chains for 49 days. The therapeutic transcutaneous electrical therapy tested was an alternating current with a continuous stimulation time setting for 20 minutes or 1 hour of therapy per dog per day at 0.5 Hertz and 500 microamperes with clip-on electrode pads for application of current. One side received electrical stimulation while the opposite side acted as a control.

Clinical tooth movement was not enhanced on the dogs that received electrical stimulation for 20 minutes per day. The specimen that received one hour per day electrical stimulation moved 50% farther in the time tested. Histological studies showed the 20 minute per day dogs and the control sides did not reveal any differences after receiving electrical stimulation. The one hour per day specimen histologically appeared to have more enhanced cellular activity. The Ca/P ratios from

the electron micro-probe on the scanning electron microscope showed slightly higher Ca/P ratios on all of the electrically stimulated specimens as compared to the controls. The compression sides on the alveolar bone in the 20 minute per day dogs showed higher Ca/P ratios than the tension sides. In the one hour per day dog the tension side showed higher Ca/P ratio than the pressure side. Radiographic comparison did not reveal any pathology or differences as a result of transcutaneous electrical stimulation.

CONCLUSIONS

A study was performed to examine the effects of transcutaneous electrical stimulation on the orthodontic movement of teeth. The number of variables tested as far as experiments are concerned was average. The transcutaneous electrical stimulation therapy employed was the intensity range most commonly used by clinicians for bioconductive therapy, that is, a continuous stimulation time at 0.5 Hertz and 500 microamperes with clip-on electrodes for application of current. The author feels that because of the findings of histological and Ca/P differences in the specimen electrically stimulated for a greater length of time per day compared to the group of dogs tested at a smaller variable of time per day that another study is needed to cover the varying lengths and repetitions of dosage application.

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VITA

Frederick F. Nolan, Jr. was born in San Antonio, Texas on June 28, 1948, the son of Lois Mae Gadbaw Nolan and Frederick F. Nolan. After graduating from Garland High School, Garland, Texas, in 1966, Dr. Nolan entered East Texas State University in Commerce, Texas, majoring in Cell Biology and English, and received the degree of Bachelor of Science in 1970. He was elected to the Beta Beta Beta Biological Honor Society and the Sigma Tau Delta Honorary Professional English Fraternity. Dr. Nolan then entered Baylor College of Dentistry at Dallas. In September of 1970, while a freshman in dental school, Dr. Nolan entered the United States Air Force Early Commissioning Program and was appointed the rank of First Lieutenant. Dr. Nolan was conferred the degree of Doctor of Dental Surgery at Baylor College of Dentistry in January of 1974. After graduation, Dr. Nolan was promoted to Captain in February of 1974 and served two years Active Duty as a Dental Officer in the 351st Combat Support Group (SAC) at Whiteman AFB Hospital, Whiteman AFB, Missouri. In 1976, Dr. Nolan was honorably separated from active duty to an Active Reserve Unit, the 9019th, as a Category B Mobilization Augmentee Dental Officer at ARPC, Denver, Colorado, assigned to Bergstrom AFB Hospital (TAC).

Bergstrom AFB, Texas and started a private general dental practice in Austin, Texas. While in private practice in Austin for 7 years, Dr. Nolan attained the rank of Major in the USAF Reserve Dental Corp. In June of 1983, Dr. Nolan entered the University of Texas Dental Branch Orthodontics Residency Program at Houston's Health Science Center and received a second year United States Air Force Institute of Technology Active Duty Sponsorship with the rank of Major. After two years of specialty residency, Dr. Nolan received the specialty certification in orthodontics and the degree of Master of Science in June, 1985.

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BRIEF SUMMARY OF THESIS

A pilot study was conducted using animal subjects that would determine if therapeutic transcutaneous electrical stimulation under the conditions tested would accelerate orthodontic tooth movement. The therapeutic range of transcutaneous electrical stimulation tested was an AC stimulation time setting which was continuous for 20 minutes or 1 hour of therapy per dog per day at a stimulation frequency of .5 Hertz and a current amplitude of 500 microamperes. Maxillary second premolars on mongrel dogs were protracted on edgewise sectional archwires using power chains. One side received transcutaneous electrical stimulation while the opposite side acted as a control.

Clinical tooth movement was enhanced in the 1 hour of therapy per day dog but not in the 20 minute per day specimens. X-ray comparisons showed no differences between the test and control sides in either group. Histological examinations revealed enhanced cellular activity in the 1 hour per day dog. Histologically, the 20 minute per day specimens and the control sides did not reveal any histological differences. The electron microprobe on the scanning electron microscope determined that the Ca/P ratios were also higher on the electrically stimulated sides than on the control sides. The Ca/P ratio of the tension side of the 1 hour per day dog was higher but in the 20 minute per day specimens the compression sides Ca/P ratios were higher when transcutaneous electrical stimulation was used in addition to orthodontic tooth movement.

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